SEMARAK ILMU PUBLISHING

Semarak Engineering Journal

Journal homepage:
https://semarakilmu.com/
ISSN: 3036-0145




# The Effect of Rising Seawater Temperature and Flow Loss Due to Fouling on A Combined Cycle Condenser Performance: A CFD Software-Based Case Study in Indonesia

Syarif Dwi Priyanto[1,*], Eflita Yohana[1], Tony Suryo Utomo[1], Muhammad Bagir[1]

[1] Department of Mechanical Engineering, Diponegoro University, Jl. Prof. Sudharto, SH., Semarang 50275, Indonesia

**ARTICLE INFO**

***Article history:***
Received 12 June 2025
Received in revised form 23 September 2025
Accepted 20 November 2025
Available online 20 January 2026

***Keywords:***
Heat recovery steam generator (HRSG); condenser fouling; cooling water flow; seawater temperature; CFD simulation; heat transport; Indonesian power plant

**ABSTRACT**

In combined cycle power plants, the condenser has a significant impact on thermal efficiency. The impact of rising seawater temperatures and flow loss due to fouling on condenser performance is investigated in this paper, which uses a case study from an Indonesian coastal power plant with a 230.3 MW Heat Recovery Steam Generator. A computational fluid dynamics (CFD)-based simulation was used to assess condenser heat duty, pressure, and cooling water (CW) characteristics at different seawater input temperatures (30°C, 31°C, 32°C) and flow rates (100%, 90%, and 80% of nominal flow). With higher CW temperature and lower flow, condenser heat absorption and generator output decrease consistently, but condenser pressure rises significantly. At 32°C input temperature and 80% CW flow, condenser pressure rose to 0.098 bara, but output fell to 229.41 MW. The CFD model successfully incorporates real-time plant data to represent dynamic interactions between temperature, fouling, and system performance, resulting in an adaptive evaluation framework appropriate for tropical regions with highly changeable marine conditions. This study emphasises the need of real-time monitoring and predictive modelling in mitigating performance degradation owing to environmental and operational stressors.

## 1. Introduction

Power plants, the primary global electricity source for 200 years since their 19th century development, continue supporting 1.5% annual energy demand growth [1,2]. A steam power plant generally comprises a feedwater tank equipped with a deaerator, a high-pressure steam boiler, high- and low-pressure steam turbines, and a water-cooled condenser, all connected sequentially within a closed-loop configuration [3]. In steam power plants, the condenser serves as a performance-critical component that significantly impacts system efficiency [4]. The efficiency and performance of thermal power plants are significantly influenced by the operational conditions of key components, with the condenser being one of the most critical. The condenser performs the critical function of recovering turbine exhaust steam by converting it back to liquid condensate, which is then reheated

[*]*Corresponding author.*
*E-mail address: syarifdwii@gmail.com*

and reintroduced into the thermal cycle [5]. The condenser's operating pressure results from the dynamic interaction of several parameters: cooling water mass flow, inlet temperature [6], fouling conditions [7] and turbine exhaust flow. These factors critically influence not just condenser efficiency but the entire system's thermal performance and power generation capacity [5]. Fouling in condenser tubes creates substantial operational and economic challenges for power stations. The fouling always grows with time, which contributes to the condenser's performance degradation, carried out researches on the fouling growth on the condenser water side wall and analyzed the characteristics of the fouling deposit, the effect of the working time and the cooling water's velocity. Condenser fouling is the appearance of deposits on the inside of the tubes. In general, fouling causes important operation and maintenance problems in facilities in contact with seawater, among them, those of the maritime sector, aquaculture, offshore utilities, etc. This fouling has negative consequences for the efficiency of the power plant and therefore for its economic balance [8].

As a very important performance indicator of a condenser, the cleanness coefficient reflects the fouling level of the condenser water-side wall, and it is an important part of the overall heat transfer coefficient of the condenser. The change of the cleanness coefficient will have a great effect on the optimization of operation and improvement of the cooling water circulation system [9].

Mariusz Markowski *et al.,* [10] proposed a new method for online measurement of fouling thermal resistance in shell and tube heat exchangers, which can be applied when the pressure, temperature, mass flow rate, and thermal physical property data of two heat exchange media are continuously available, and a sensitivity analysis was conducted on this method. Furthermore, the cooling water (CW) temperature at the condenser inlet fluctuates according to seasonal changes in air and seawater conditions, following the natural annual temperature cycle of the intake system. In tropical coastal regions like Indonesia, these temperature fluctuations can be more significant due to changes in sea surface temperature influenced by climate patterns, tides, and oceanographic factors.

This study investigates of effect of increasing seawater temperature and the drop in cooling water (CW) flow rate—mainly as a result of fouling—on the thermal performance of combined cycle condensers is the objective of this study. A heat recovery steam generator (HRSG) capacity of 230.3 MW, a power plant in Indonesia is chosen as a case study where the performance is simulated using a CFD-based modelling tool. Analytical parameters assessed include heat transfer rate, condenser pressure, and the CW velocity, along with overall flow rate. A computational framework was constructed to establish dynamic relationships between heat transfer coefficients, thermal loads, system efficiency, and CW circulation measures. Unlike previous models that rely on set empirical constants, the proposed method provides real-time performance prediction utilizing existing factory data, such as CW inlet temperature and flow rate. This model's dynamic nature allows for adaptive performance assessment under a variety of ambient and operating conditions, which is especially useful in tropical coastal locations where seawater temperature and fouling often vary.

## 2. Methodology

### *2.1 System Model*

In this study, the simulated system is based on a heat recovery steam generator (HRSG), operating along Indonesia's coast, with a heat recovery steam generator (HRSG) capacity of roughly 230.3 MW. The plant's configuration includes a heat recovery steam generator (HRSG) and a steam turbine (ST) with stages for high-pressure (HP) and low-pressure (LP). The condenser, which served as a shell and tube heat exchanger, is an important part of the lower steam cycle. Steam discharged from the LP turbine and entered the shell side of the condenser, while seawater, used as cooling water (CW) that flowed through the tube side via tube sheets. The condenser is equipped with 15,600 welded tubes

made from titanium, providing high resistance to corrosion and biofouling in a marine environment. The total heat exchange surface area is approximately 13667.6 m². Under nominal operating conditions, the condenser pressure is maintained at 85 mbara or 0.085 bara, with a CW inlet temperature of 30°C and CW inlet flow 15035 kg/s. Detailed illustrated heat recovery steam generator (HRSG) with Condenser and thermal design specification are presented in Table 1, and the schematic layout of the condenser configuration is illustrated in Figure 1. illustrated heat recovery steam generator (HRSG) with condenser.

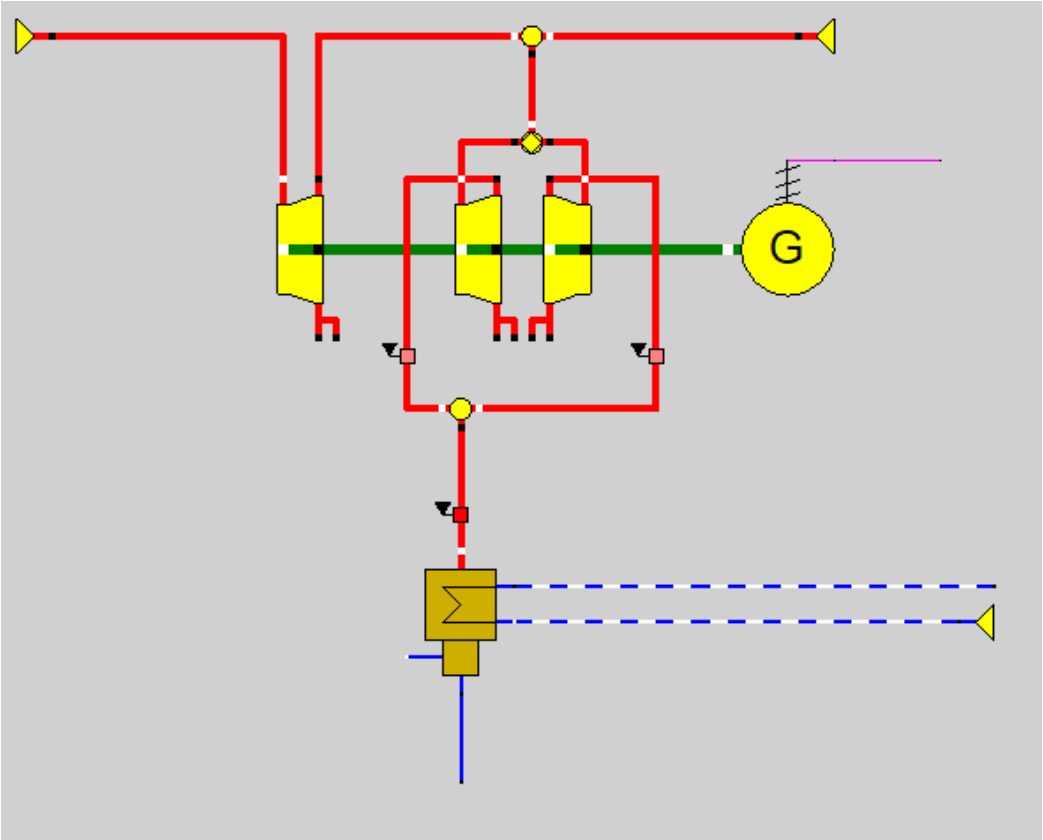



**Fig. 1.** Illustration of heat recovery steam generator (HRSG) with condenser

**Table 1**
Specification of the condenser

| Name | Value |
|---|---|
| Type | Steam surface condenser |
| Surface area | 13667.6 m2 |
| Heat Duty design | $0.46982\times10^{9}$ W |
| Exhaust pressure | 85 mbar(abs) |
| Cooling water Flow | 15035 kg/s |
| Cooling water Temperature | 30 degC |
| Vacuum | 85 mbar (abs) |

### *2.2 Thermal Performance Analysis*

The condenser, a large shell-and-tube heat exchanger, plays a critical role in the thermodynamic cycle by facilitating the phase transition of steam from vapor to liquid. As external cooling water flows through thousands of tubes within the condenser, it carries away the latent heat released during condensation [11]. Maintaining low pressure in the condenser is essential for operational efficiency

and is made possible through this continuous heat rejection. The thermal energy absorbed by the cooling water reflects not only a transfer of energy, but also humanity's broader challenge to manage energy sustainably while minimizing environmental impact. The rise in the cooling water's temperature and its mass flow rate [12] correspond directly to the heat removed from the system, governed by:

The calculation is based on the thermal balance of the steam condenser [13], calculated from Eq. (1):

$$Q = \dot{m}_{cw}\,(C_p)_{cw}\,(T_{cwout} - T_{cwin}) = \dot{m}_s\,(h_s - h_{cond}) \quad (1)$$

Based on the equation, the value of cooling water heat absorption is obtained with the following Eq. (2) [7]:

$$Q_{Cw} = \dot{m}_{cw}\,(C_p)_{cw}\,(T_{cwout} - T_{cwin})) \quad (2)$$

$\dot{m}_{cw}$ = Cooling water mass flow rate (kg/s)
$(C_p)_{cw}$ = Specific heat of water (4.18 kJ/kg°C)
$\Delta T_{cw}$ = Temperature rise of cooling water (°C)
$\dot{m}_s$ = Steam mass flow rate (kg/s)
$h_s$ = Enthalpy of inlet steam (kJ/kg)
$h_{cond}$ = Enthalpy of condensate (kJ/kg)

Another relation for Q defines the problem completely. These deposits have low thermal conductivity and therefore result in lower overall conductance (UA) as well as effectiveness of the heat exchanger [14]. If the surface area of the condenser tubes is A and the overall heat transfer coefficient is U, then Q can be expressed as eq. (3) [15,16] :

$$Q = \mathrm{U\ A}\ \Delta T_{ln} \quad (3)$$

U =Heat Transfer Coefficient (W/m2K)
A =Heat transfer surface area (m²)
$\Delta T_{ln}$ =Log Mean Temperature Difference (°C)

The logarithmic mean temperature difference (LMTD) is [17], calculated from Eq. (4):

$$\Delta T_{lm} = \frac{(T_S - T_{cwin}) - (T_S - T_{cwout})}{\ln \frac{(T_S - T_{cwin})}{(T_S - T_{cwout})}} \quad (4)$$

$T_s$ = Saturation temperature of steam (°C)
$T_{cwout}/T_{cwin}$ = outlet/inlet CW temperatures (°C)

Inside overall heat transfer coefficient with fouling: The inside overall heat transfer coefficient of seawater, U changes as a function of both temperature and fouling factor [18]. The heat transfer coefficient U can be estimated as Eq. (5) [6].

U : U1×FW×FM×FC [9] (5)

U ：Heat Transfer Coefficient (W/m2K)
$U_1$ : Uncorrected Heat Transfer Coefficients（Figure.1）
$F_W$ ： Inlet Water Temperature Correction Factor（Figure.2）
$F_M$ ： Tube Material and Gauge Correction Factor（Table.3）
$F_C$ ： Cleanliness Factor

The factors $F_W$ and $U_1$ depend dynamically on the problem and have to be evaluated within the problem domain, whereas FM is a constant. Cleanliness factor (Fc) can be treated as a constant for the problem. Eqs. (1)e(3) need to be solved consistently to generate the heat load on the condenser. To address this issue, knowledge of the following inputs is required: enthalpy and mass flow rate of steam from turbine output and additional sources, inlet water temperature of the cooler, specific heat, and condenser parameters U1, FW, FM, FC, and A.

*2.3 Variations in inlet CW temperature*

Condenser efficiency is strongly influenced by variations in seawater input temperature [11], which result from annual and seasonal fluctuations in the intake system. Seawater surface temperature at Indonesian coastal power facilities can vary by several degrees Celsius over the course of a year. These temperature changes influence the temperature gradient across the condenser and thus the net heat transfer rate.

*2.4 Simulation Scenario*

The simulation scenarios in this study were carried out using Professional CFD Software, which included real operational data and variation simulated flow, cooling water inlet. Using simulation software, the heat recovery steam generator (HRSG) system is modelled with varying cooling water inlet temperatures.

i. Simulation and validation using a heat balance of 100%.
ii. Increase in cooling water inlet temperature and decrease in cooling water inlet flow with reference to CW inlet temperature.

The simulation scenarios in this study were carried out using CFD, as shown in Table 2. Variable simulation based on cooling water inlet temperature & cooling water inlet flow.

**Table 2**
Variable simulation based on cooling water inlet temperature & cooling water inlet flow

| Variable CW In temperature | Variable CW In % flow | Flow rate Cooling water (kg/s) |
|---|---|---|
| 30 | 100 % | 15035 |
| 30 | 90 % | 13531.5 |
| 30 | 80 % | 12028 |
| 31 | 100 % | 15035 |
| 31 | 90 % | 13531.5 |
| 31 | 80 % | 12028 |
| 32 | 100 % | 15035 |
| 32 | 90 % | 13531.5 |
| 32 | 80 % | 12028 |

## 3. Results

### *3.1 Results and Discussion*

Here are the heat recovery steam generator (HRSG) variables at Heat balance 100% data vs Simulation. The results Simulation of heat recovery steam generator (HRSG) variables at Heat balance 100% shown in Figure 2.

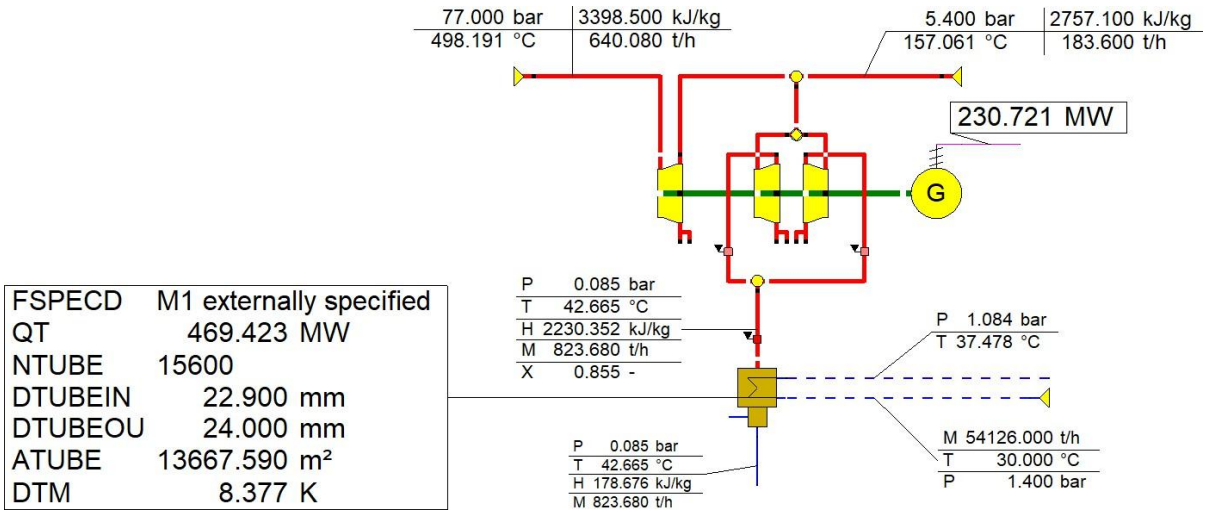



**Fig. 1.** Simulated based on data heat recovery steam generator (HRSG) variables at Heat balance 100%

Validation of simulated based of data heat recovery steam generator (HRSG) variables at Heat balance 100%, shown in Table 3. Validation of simulated based of data heat recovery steam generator (HRSG) variables at Heat balance 100%.

**Table 3**
Validation of simulated based of data heat recovery steam generator (HRSG) variables at Heat balance 100%

| | T Cooling water inlet °C | T Cooling water outlet °C | M Cooling water inlet kg/s | Q condenser (MW) | P Condenser (bara) | T Condenser °C |
|---|---|---|---|---|---|---|
| Simulation | 30.00 | 37.48 | 15035.00 | 469.42 | 85.00 | 42.67 |
| Data Heat Balance or Specification of Condenser | 30.00 | 37.80 | 15035.00 | 469.82 | 85.00 | 42.70 |
| Validation | 0.00% | 0.85% | 0.00% | 0.08% | 0.00% | 0.08% |

Here are the heat recovery steam generator (HRSG) variables at 100% flow rate and cooling water inlet temperature variations (30°C, 31°C, and 32°C). The results from the heat balance data and condenser simulation with a cooling water inlet flow of 100% or 15035 kg/s and a cooling water inlet temperature of 30°C are heat to condenser: 469.42 MW, condenser vacuum: 0.085 bar, and generator output: 230.72 MW.

The results from the heat balance data and condenser simulation with a cooling water inlet flow of 100% or 15035 kg/s and a cooling water inlet temperature of 31°C are heat to condenser: 469.01 MW, condenser vacuum 0.089 bar, and generator output 230.3 MW. The simulation results for the cooling water inlet flow at 100% or 15035 kg/s, with a cooling water inlet temperature of 32°C, are heat to condenser: 468.71 MW, condenser vacuum: 0.092 bar, and generator output: 229.99 MW.

The simulation results for a flow of 100% and variations in cooling water inlet temperature (30°C 3°C, and 32°C) are shown in Table 2.

**Table 3**
Variable simulation based on cooling water inlet temperature (30°C, 31°C & 32°C) & cooling water inlet flow of 100 % or 15035 kg/s

| T Cooling water inlet °C | T Cooling water outlet °C | M Cooling water inlet kg/s | Q condenser (MW) | P Condenser (bara) | T Condenser °C | LMTD K |
|---|---|---|---|---|---|---|
| 30.00 | 37.478 | 15035 | 469.423 | 85.00 | 42.67 | 8.377 |
| 31.00 | 38.471 | 15035 | 469.009 | 89.00 | 43.55 | 8.255 |
| 32.00 | 39.467 | 15035 | 468.709 | 92.00 | 44.19 | 7.871 |

Here are the heat recovery steam generator (HRSG) variables at 90% flow rate and cooling water inlet temperature variations (30°C, 31°C, and 32°C). The results from the heat balance data and condenser simulation with a cooling water inlet flow of 90% or 13531 kg/s and a cooling water inlet temperature of 30°C are heat to condenser: 469.11 MW, condenser vacuum: 0.088 bar, and generator output: 230.4 MW. The results from the heat balance data and condenser simulation with a cooling water inlet flow of 90% or 13531 kg/s and a cooling water inlet temperature of 31°C are heat to condenser: 468.81 MW, condenser vacuum 0.091 bar, and generator output 230.09 MW. The simulation results for the cooling water inlet flow at 90% or 13531 kg/s, with a cooling water inlet temperature of 32°C, are heat to condenser: 468.51 MW, condenser vacuum: 0.094 bar, and generator output: 229.79 MW. The simulation results for a flow of 90% and variations in cooling water inlet temperature (30°C, 3°C, and 32°C) are shown in Table 4.

**Table 4**
Variable simulation based on cooling water inlet temperature (30°C, 31°C & 32°C) & cooling water inlet Flow 90 % or 13531.5 kg/s

| T Cooling water inlet °C | T Cooling water outlet °C | M Cooling water inlet kg/s | Q condenser (MW) | P Condenser (bara) | T Condenser °C | LMTD K |
|---|---|---|---|---|---|---|
| 30.00 | 38.302 | 13531.5 | 469.11 | 88.00 | 43.33 | 8.514 |
| 31.00 | 39.297 | 13531.5 | 468.81 | 91.00 | 43.98 | 8.133 |
| 32.00 | 40.292 | 13531.5 | 468.51 | 94.00 | 44.60 | 7.729 |

Here are the heat recovery steam generator (HRSG) variables at 80% flow rate and cooling water inlet temperature variations (30°C, 31°C, and 32°C). The results from the heat balance data and condenser simulation with a cooling water inlet flow of 80% or 12028 kg/s and a cooling water inlet temperature of 30°C are heat to condenser: 468.81 MW, condenser vacuum: 0.091 bar, and generator output: 230.09 MW. The results from the heat balance data and condenser simulation with a cooling water inlet flow of 80% or 12028 kg/s and a cooling water inlet temperature of 31°C are heat to condenser: 468.42 MW, condenser vacuum 0.095 bar, and generator output 229.7 MW. The simulation results for the cooling water inlet flow at 80% or 12028 kg/s with a cooling water inlet temperature of 32°C are heat to condenser: 468.13 MW, condenser vacuum: 0.098 bar, and generator output: 229.41 MW. The simulation results for a flow of 80% and variations in cooling water inlet temperature (30°C, 3°C, and 32°C) are shown in Table 3.

**Table 5**
Variable simulation based on cooling water inlet temperature (30°C, 31°C & 32°C) & cooling water inlet Flow 80 % or 12028 kg/s

| T Cooling water inlet °C | T Cooling water outlet °C | M Cooling water inlet kg/s | Q condenser (MW) | P Condenser (bara) | T Condenser °C | LMTD K |
|---|---|---|---|---|---|---|
| 30.00 | 39.33 | 12028 | 468.81 | 91.00 | 43.98 | 8.468 |
| 31.00 | 40.326 | 12028 | 468.42 | 95.00 | 44.81 | 8.288 |
| 32.00 | 41.321 | 12028 | 468.13 | 98.00 | 45.41 | 7.852 |

## 4. Conclusions

A CFD-based investigation of the effects of elevated seawater temperatures and fouling-driven cooling water flow reduction on condenser performance is conducted for a tropical combined-cycle power plant in Indonesia. The key findings include:

i. Temperature Effect: A 2°C rise in CW inlet temperature reduces condenser heat transfer and raises pressure from 0.085 to 0.092 bara at maximum flow, lowering generator output by about 0.73 MW.
ii. Flow Rate Reduction: Reducing the nominal CW flow from 100% to 80% affects performance significantly, with condenser vacuum rising to 0.098 bara and output dropping by more than 1.3 MW.
iii. Dynamic Performance Modelling: The CFD model effectively captures the thermohydraulic interactions within the condenser, dynamically adapting for temperature changes and fouling-induced flow losses.
iv. Operational Implication: To achieve sustained performance, seawater temperature and fouling levels must be continuously monitored. The created model is a useful predictive tool for planning maintenance schedules, optimising operations, and reducing energy losses in tropical maritime environments.

Future study could expand the model to include biological fouling impacts and long-term operational deterioration projections in order to improve plant reliability and economic sustainability.

**Acknowledgement**
This research was not funded by any grant.

**Conflict of Interest Statement**
The authors declare that there is no conflict of interest regarding the publication of this paper. No financial support, grants, or other forms of compensation were received that could have influenced the outcomes of this work. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Author Contributions Statement**
Syarif Dwi Priyanto Conceptualization, Methodology, Software, Data curation, Writing – Original draft preparation. Eflita Yohana Supervision, Validation, Writing – Reviewing and Editing. Tony Suryo Utomo Resources, Supervision, Writing – Reviewing and Editing. Muhammad Bagir Visualization, Investigation.

## Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request. Where applicable, publicly available datasets used in the study are cited in the references.

## Ethics Statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee. Ethical approval was obtained where required, and informed consent was obtained from all participants involved in the research.

## References

[1] Khattak, M. A., M. A. Ashraf, M. Ikmal, A. Syafiq, and M. Hazritz. "Common types of fuels in steam power plant: a review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 23, no. 1 (2016): 1-24.

[2] E. Yohana, W. Firmansah, M. Farkhan, H. Dwinanda, and M. Endy, "Multi-stage Steam Turbine Energy and Exergy Analysis at PT. XYZ 625 MW using HYSYS Software," vol. 1, no. 1, pp. 15–29, 2025. https://doi.org/10.37934/arnht.33.3.1529

[3] Mohammed, Mohammed Kamil, Wadhah Hussein Al Doori, Ataalah Hussain Jassim, Thamir Khalil Ibrahim, and Ahmed Tawfeeq Al-Sammarraie. "Energy and exergy analysis of the steam power plant based on effect the numbers of feed water heater." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 56, no. 2 (2019): 211-222.

[4] Poškas, Robertas, Arūnas Sirvydas, Laura Mingilaitė, Povilas Poškas, and Hussam Jouhara. "Investigation of effect of cooling water characteristics on flue gas condensation along vertical tube heat exchanger." *Energy* 289 (2024): 130046. https://doi.org/10.1016/j.energy.2023.130046

[5] Chen, Dong, Wenjie Zhang, Xiaoze Du, Lei Xu, and Huimin Wei. "Dynamic optimization method for cleaning cycle of condenser of nuclear power plant." *Energy* 294 (2024): 130814. https://doi.org/10.1016/j.energy.2024.130814

[6] Ibrahim, Said MA, and Sami I. Attia. "The influence of condenser cooling seawater fouling on the thermal performance of a nuclear power plant." *Annals of Nuclear Energy* 76 (2015): 421-430. https://doi.org/10.1016/j.anucene.2014.10.018

[7] Attia, Sami I. "The influence of condenser cooling water temperature on the thermal efficiency of a nuclear power plant." *Annals of Nuclear Energy* 80 (2015): 371-378. https://doi.org/10.1016/j.anucene.2015.02.023

[8] Li, Jianlan, Zhaoyin Zhai, Jizhou Wang, and Shuhong Huang. "On-line fouling monitoring model of condenser in coal-fired power plants." *Applied Thermal Engineering* 104 (2016): 628-635. https://doi.org/10.1016/j.applthermaleng.2016.04.131

[9] Vodeniktov, Artem, Azamat Minibaev, Valeriia Melnikova, Kirill Egorochkin, Arseny Samoilov, and Aleksandr Ovechkin. "The problem of the surface condenser overall heat transfer coefficient determining at high temperatures of cooling water." *Results in Engineering* 18 (2023): 101193. https://doi.org/10.1016/j.rineng.2023.101193

[10] Markowski, Mariusz, Marian Trafczynski, and Krzysztof Urbaniec. "Validation of the method for determination of the thermal resistance of fouling in shell and tube heat exchangers." *Energy Conversion and Management* 76 (2013): 307-313. https://doi.org/10.1016/j.enconman.2013.07.052

[11] Pattanayak, Lalatendu, Biranchi Narayana Padhi, and Bibhakar Kodamasingh. "Thermal performance assessment of steam surface condenser." *Case Studies in Thermal Engineering* 14 (2019): 100484. https://doi.org/10.1016/j.csite.2019.100484

[12] Anozie, A. N., and O. J. Odejobi. "The search for optimum condenser cooling water flow rate in a thermal power plant." *Applied Thermal Engineering* 31, no. 17-18 (2011): 4083-4090. https://doi.org/10.1016/j.applthermaleng.2011.08.014

[13] Laskowski, Rafał, Adam Smyk, Artur Rusowicz, and Andrzej Grzebielec. "A useful formulas to describe the performance of a steam condenser in off-design conditions." *Energy* 204 (2020): 117910. https://doi.org/10.1016/j.energy.2020.117910

[14] Qureshi, Bilal Ahmed, and Syed M. Zubair. "Predicting the impact of heat exchanger fouling in power systems." *Energy* 107 (2016): 595-602. https://doi.org/10.1016/j.energy.2016.04.032

[15] Prieto González, María Manuela, Juan M. Vallina, Inés María Suárez Ramón, and I. Martín. "Application of a design code for estimating fouling on-line in a power plant condenser cooled by seawater." *Experimental Thermal and Fluid Science, 25 (5)* (2001). https://doi.org/10.1016/S0894-1777(01)00081-4

[16] Laskowski, Rafał. "Relations for steam power plant condenser performance in off-design conditions in the function of inlet parameters and those relevant in reference conditions." *Applied Thermal Engineering* 103 (2016): 528-536. https://doi.org/10.1016/j.applthermaleng.2016.04.127
[17] Hu, Hemin, Tao Wang, Yufei Ren, Fan Zhang, Bing Zhang, and Jianchao Li. "A case study of thermal performance of gas-steam combined cycle with gas turbine inlet air cooling and condenser deep cooling." *Case Studies in Thermal Engineering* 60 (2024): 104747. https://doi.org/10.1016/j.csite.2024.104747
[18] Wang, Lei, Ruiqing Zhang, Zenghong Xiao, and Yongjun Xia. "Study on the time decreasing trend model of condenser cleanness coefficient." *Energy Procedia* 16 (2012): 1860-1867. https://doi.org/10.1016/j.egypro.2012.01.285